

## HIGH TEMPERATURE PLAGIOCLASES FROM THE TERTIARY VOLCANIC ROCKS OF CENTRAL VICTORIA

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### Abstract

The distribution of alkali feldspars in basic rocks of the Newer Volcanic series of Victoria has been overestimated. The plagioclases of the various basic rocks were formed under similar thermal conditions, and show a close affiliation with the rocks in which they occur. The lime content of the rocks is controlled by the plagioclases and pyroxenes in an interdependent relationship. In these rocks the potassium content of the plagioclases was determined mainly by the extent of reaction between the residual potash-rich solution and the plagioclase at low temperatures. Infrared data for plagioclases are utilized for paragenetic considerations.

### Introduction

Thirty-three plagioclases were separated from various volcanic rocks of the Newer Volcanic Series of the Tertiary alkaline province in Central Victoria. All the samples were examined twice, each time with a new mount, by the X-ray powder method in the range of  $2\theta = 20^\circ$ — $32^\circ$ . Twelve plagioclase samples which were satisfactorily purified, representing a reasonably wide composition range of the volcanic rocks, and showing sharp reflections in X-ray patterns (Fig. 1), were chemically analyzed in duplicate for CaO, Na<sub>2</sub>O, and K<sub>2</sub>O. Ca was determined by a titrimetric method with E.D.T.A., and calcein mixture indicator. The alkalis were determined by flame photometry. Ten representative samples were examined by infrared absorption. The results are presented and discussed below (Table I).

### Anorthoclase in Basic Rocks

It was realized from X-ray patterns, that only in rare cases were alkali feldspar phenocrysts a large proportion of the feldspars in these basic rocks, despite the fact that in some trachybasalts (at Turpin's Falls) plagioclase phenocrysts had been previously identified as anorthoclases on optical data (Edwards 1938). In some basic rocks occasional highly resorbed alkali feldspars do occur. They are particularly common in some basalts NE. of Woodend near Sugarloaf Hill. As indicated by studying the relief of such feldspars, resorbed plagioclases are sometimes associated with resorbed alkali feldspars. On the present evidence, it would seem that the distribution of alkali feldspars in basic rocks has been overestimated, and accordingly it is suggested that the rocks defined by Edwards as anorthoclase basalts, should be renamed alkali feldspar-bearing basalts.

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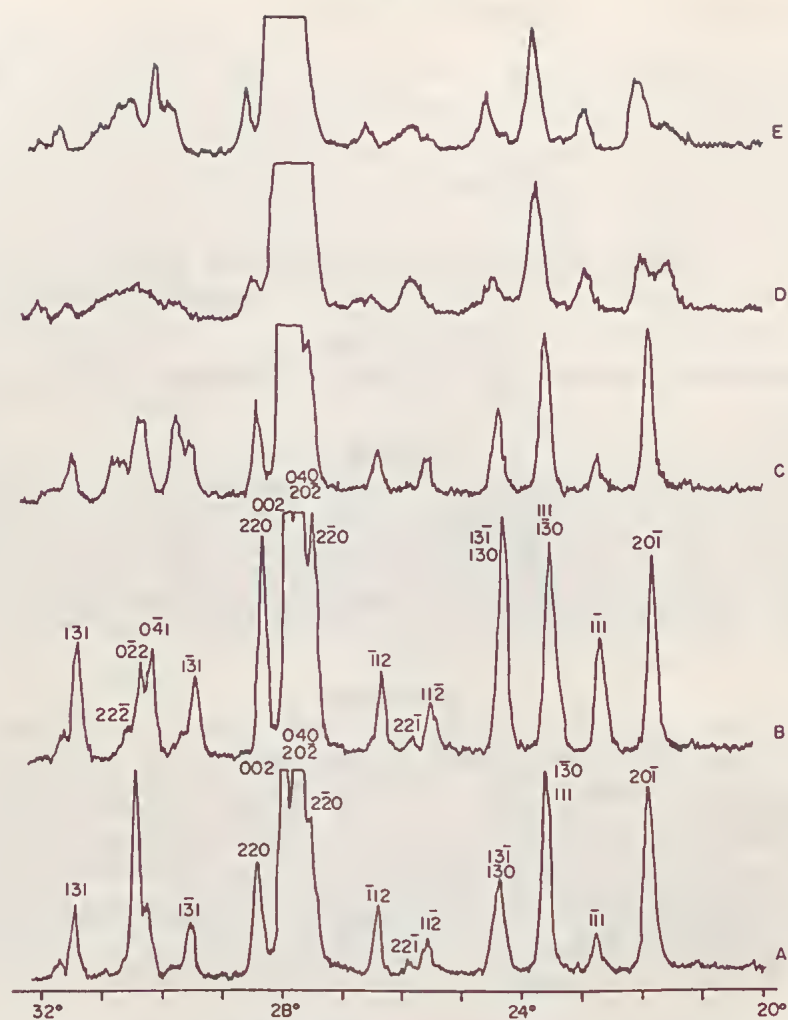


FIG. 1—X-ray powder patterns of high-temperature plagioclases. A and B are typical patterns of plagioclases which are considered to have been successfully separated from their rocks (Nos. 11 and 5 respectively). C, D and E are patterns of plagioclases which are considered to have been unsuccessfully separated from their rocks, and therefore discarded from further investigation. These plagioclases are from basalt, macedonite and trachybasalt respectively.

### The Thermal State

The variation of  $2\theta(1\bar{3}1) - 2\theta(131)$  with composition of the plagioclases is shown in Fig. 2 (after Smith & Yoder 1956). All the plagioclases investigated from the Victorian rocks fall between the high and low temperature lines, as might be expected, with the exception of samples Nos 1 and 10 (Table I), which fall on the high temperature line. Thus, it is inferred that most of the plagioclases were formed in a similar thermal state.

TABLE 1  
CHEMICAL AND X-RAY DATA ON HIGH TEMPERATURE PLAGIOCLASES

No.	Position of Rock*	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	An	Ab	Or	Total	$\frac{\text{An}}{\text{An}+\text{Ab}+\text{Or}}$	( $\overline{131}$ ) - (131)
1	-3.09	10.03	5.39	0.82	49.76	45.61	4.85	100.22	49.65	1.98
2	-2.00	11.53	4.54	0.44	57.19	38.44	2.60	98.23	58.22	1.99
3	-1.68	12.19	4.46	0.26	60.47	37.57	1.52	99.56	60.74	2.03
4	-1.42	10.83	4.90	0.62	53.72	41.47	3.67	98.86	54.34	1.97
5	-1.33	9.22	5.61	1.21	45.74	47.47	7.15	100.36	45.58	1.89
6	-0.58	12.14	4.27	0.56	60.25	36.11	3.31	99.67	60.45	1.98
7	0.06	10.35	4.79	1.16	51.35	40.32	6.87	98.54	52.11	1.85
8	0.63	11.89	4.72	0.24	58.97	39.92	1.43	100.32	58.78	1.95
9	0.80	9.73	5.39	0.97	48.28	45.59	5.73	99.60	48.47	1.89
10	3.38	8.80	10.32	0.60	43.65	51.18	3.52	98.35	44.38	1.96
11	5.52	9.54	5.28	1.11	47.31	44.68	6.57	98.56	48.00	1.92
12	5.74	8.85	5.39	1.63	43.90	45.61	9.65	99.16	44.27	1.88

\* Position of rock is determined by  $(\text{Si}/3 + \text{K}) - (\text{Ca} + \text{Mg})$   
(Nockolds & Allen, 1953).

*Notes on origin of specimens:*

1. Coarse feldspathic basalt, Mt Porndon; 2. Basalt, Springfield; 3. Near the road between Sydenham and Digger's Rest; 4. Basalt, Trentham Falls; 5. Basalt, SW. of Kyneton; 6. Basalt, Gisborne; 7. Basalt, Mt Anakie (western peak); 8. Basalt, Mt Gorong; 9. Basalt, W. of Newham; 10. Trachybasalt, Turpin's Falls; 11. Maccdonite, Melbourne Hill; 12. Macedonite, Gisborne.

**Anorthitic Content of the Plagioclases**

The variation of the plagioclase composition with the position of the rock as it is determined by  $(\text{Si}/3 + \text{K}) - (\text{Ca} + \text{Mg})$ , (Nockolds & Allen 1953) is shown in Fig. 3. An expected trend can be observed: the more basic the position of the rock, the higher is the anorthite content of the plagioclase. Larsen *et al.* (1938a) studied the plagioclase feldspars from the Tertiary volcanic rocks of the San Juan Region in Colorado, and decided that many of the phenocrysts were foreign to the rocks in which they were present. They based this conclusion on several factors. One was the surprisingly slight relationship between composition of plagioclase phenocrysts and composition of rock or groundmass. The plagioclases in Central Victoria show much closer affinity to the rocks than do the plagioclases of the San

Juan Region. They were derived from the same magma from which the rocks were crystallized. However, in Victoria there is considerable scattering around the curve correlating the anorthite content of the plagioclase with the position of the rock. When this result is compared with the almost linear correlation obtained by plotting the calcium content against position of the rock (writer's unpublished Ph.D. thesis), it is apparent that the lime content of these rocks is not controlled by only the plagioclases. Control is exercised also by other minerals, mainly pyroxenes. Carmichael (1960) reached similar conclusions; he found a lack of equivalence between the fractionation stage of the pyroxene phenocrysts and the fractionation stage of the feldspar phenocrysts in some British and Icelandic Tertiary acid glasses. Carmichael's explanation was that, possibly due to difference in temperature of crystallization, 'the early separation of a calcium-rich pyroxene in varying amounts may cause variation in the  $\text{CaO}:\text{Na}_2\text{O}$  ratio of the liquid, so that to a limited extent the anorthite content of a later-separating plagioclase may be controlled by the amount of the calcium-rich pyroxene separating.'

### Orthoclase Content of the Plagioclases

The orthoclase content of the plagioclases varies between 1.43% and 9.65%. This variation with respect to the position of the rock, is shown in Fig. 3. There is no systematic change in the orthoclase content, but generally, the more acid rocks have plagioclases with higher content of potash. A similar trend was observed by Larsen *et al.* (1938b). When Fig. 3 is compared with the curve obtained by plotting the potassium content of the rock against the position of the rock (Bahat, above), it appears that whereas in the various basic rocks the potassium content is steadily changing, in the respective plagioclases there is a pronounced variation in potash content. Tuttle and Bowen (1958) demonstrated that lime-rich high-temperature alkali feldspars from trachytes had been plagioclases, which reacted with potash-rich solutions in late stages of the trachytic magmatic evolution. In a similar way, it is suggested that potash-rich plagioclases from macedonite rocks (Samples Nos 11 and 12) reacted with the residual potash-rich solution prior to the final crystal-

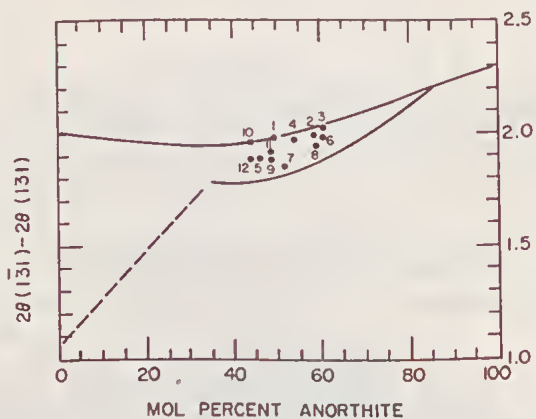


FIG. 2—Variation of  $2\theta(\bar{1}\bar{3}1) - (131)$  with composition in plagioclases (shown by solid circles). Per cent anorthite is calculated as  $\frac{An}{An + Ab + Or}$ . The upper line is produced by synthesized plagioclases, the lower line is produced by plagioclases from thick stratiform mafic intrusions (Smith & Yoder 1956).

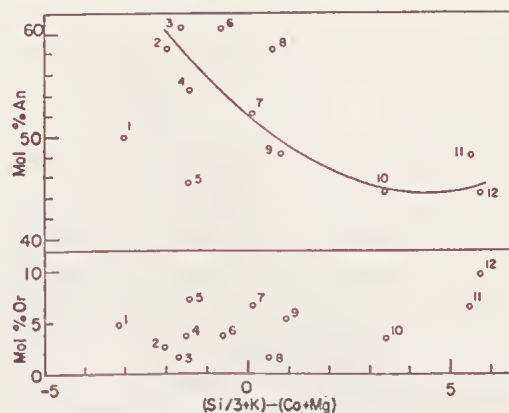


FIG. 3—In the upper part of the figure, variation of mol per cent anorthite in plagioclase with the position of the rock. In the lower part of the figure, variation of mol per cent orthoclase in plagioclase with the position of the rock. The position of the rock is determined by  $(Si/3 + K) - (Ca + Mg)$  (Nockolds & Allen 1953).

lization. Thus, in these rocks the plagioclases became rich in potash because (a) these rocks were potash-rich, hence there was higher availability of potash for reaction with the plagioclases; (b) a considerable amount of potash was left available in solution for late reaction of the plagioclases, through some process which did not enable the potash to be introduced into minerals other than plagioclases.

The latter condition (b) should apply mainly to the more basic rocks and this assumption is confirmed by the petrography. The potash content is quite similar in these various rocks but they are characterized by different textures. Rocks Nos 3 and 8, which have plagioclases with low potash content are also typified by a groundmass rich in glass, which must be rich in potash, because of the content in the rock analysis. Thus, the late stage of the rock crystallization could not have permitted a reaction between the plagioclase and the solution. For some unknown reason, these rocks are pyroxene-poor. The basalts having potash-rich plagioclases, Nos 5, 7 and 9, are holocrystalline and are rich in pyroxenes. It is considered that in these rocks the plagioclases had opportunity to react with the potash-rich solution. Thus it can be concluded that the potash content in high-temperature plagioclases is determined by the availability of potash and by the crystallization process, which resolves the extent of late reaction between the plagioclase and the solution.

Sen (1959) investigated the potash content of natural plagioclases. He found a definite trend of increasing potassium content with increasing temperature of formation from amphibolite facies, granulite facies and volcanic rocks. He also concluded that availability is important—an increased relative concentration of potassium in the environment will enrich the plagioclase in potassium to a point which will be determined by the limit of solubility. His second conclusion is supported by the present results. When Sen's first conclusion is considered, it appears that although in various rock series (amphibolite, granulite, and volcanic rocks) there is a trend towards increasing potassium content with increasing temperature, in the volcanic rocks the extent of reaction at low temperatures determines the potassium content of the plagioclases.

Muir & Tilley (1961) pointed out that hawaiites and mugearites are characterized by strongly zoned feldspars, ranging from calcic andesine to lime anorthoclase in hawaiites, becoming more sodic in mugearites. The plagioclases separated from

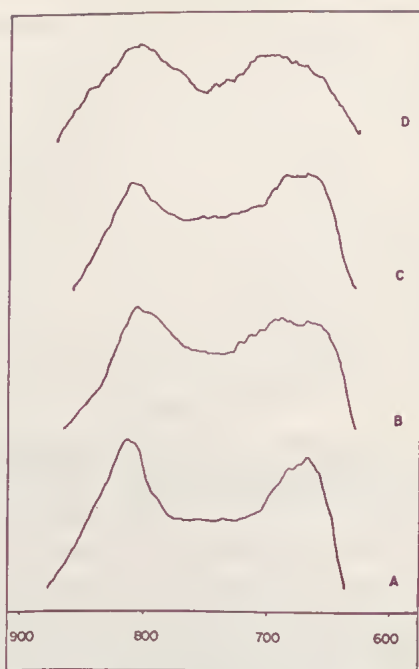


FIG. 4—Infrared patterns of plagioclases from various volcanic rocks in Victoria, in the frequency range 600-900  $\text{cm}^{-1}$ . A—Macedonite, Melbourne Hill. B—Basalt, Holder. C—Basalt, N. of Benambra. D—A basic rock, Mt Beauty.

the macedonites (Nos 11 and 12) are as basic as An 47.31 and An 43.90. This composition corresponds to the central portion of large, strongly zoned plagioclases from mugearites described by Muir & Tilley. The Or content of the plagioclases separated from the macedonites is comparable to the Or content of the plagioclase fractions of feldspars from mugearites described by Muir & Tilley (1961 Table II, Analyses 13, a, 15, a).

Fig. 1D is an X-ray pattern of a plagioclase which was incompletely separated from a macedonite and therefore discarded from further investigation. Fig. 1B on the other hand is a pattern of a plagioclase which was successfully separated from another macedonite (sample No. 11). The same separation method was used for all the rocks of the present investigation (Frantz Isodynamic Magnetic Separator), yet the results were different, due to differences in zoning. As was shown by Muir & Tilley, the present X-ray data indicate that in these basic-intermediate rocks, which are comparatively potash-rich, one should expect considerable variations in composition and zoning phenomena in feldspars, probably due to variations in cooling histories.

#### Infrared Investigation

Thompson & Wadsworth (1957) correlated shifts in absorption peak locations with certain structural changes in plagioclases. Hafner & Laves (1957) distinguished between low and high temperature plagioclases according to changes in infrared absorption bands. It is expected that different plagioclases of a given composition will show variations in their infrared absorption patterns, corresponding to differences in their thermal histories.

Figs 4A, B show typical infrared patterns of plagioclases from the Newer Volcanic series in Central Victoria. Variations in patterns of plagioclases in this province are characterized by different intensities of the broad peak in the  $750\text{ cm}^{-1}$  region. Fig. 4D shows an infrared pattern of a plagioclase which was separated from a volcanic rock collected near Mt Beauty. Unfortunately this rock was not *in situ*, but it could be of Palaeozoic age. The infrared pattern is quite different, although the rock specimen resembles a basalt from Central Victoria. Fig. 4C shows an infrared pattern of a plagioclase separated from a basalt collected in East Victoria, N. of Benambra. The difference between this pattern and those of the plagioclases from Central Victoria is not so pronounced; still there is an obvious difference. The plagioclase from North Benambra is the only one which is characterized by having an absorption peak at  $675\text{ cm}^{-1}$ , which is deeper than the absorption peak in the  $825\text{ cm}^{-1}$  region. This suggests that the basalt from north of Benambra has had a different thermal history from the basalts of Central Victoria, implying that the lavas from N. of Benambra do not have affinities with the Newer Volcanic series of Central Victoria.

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